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Crustal Structure Beneath Hudson Bay from Ambient-noise Tomography - Implications for basin formation

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SUMMARY

The Hudson Bay basin is the least studied of the four major Phanerozoic intracratonic basins in North America, which include the hydrocarbon-rich Williston, Illinois and Michigan basins. This study focuses on determining how the Hudson Bay basin formed and on regional crustal structure based on ambient-noise tomography. Two hypotheses are tested, the first suggesting subsidence due to eclogite phase transformation and the second suggests subsidence from lithospheric extension resulting in crustal thinning. Results show asymmetric cross-correlation functions, for which we have adopted an alternative method to averaging cross-correlations, yielding better-defined dispersion ridges. Tomographic pseudo-sections show compelling evidence suggesting crustal thinning as the main event in basin formation.

Introduction

The Hudson Bay basin is the least studied of the four major Phanerozoic intracratonic basins in North America, which include the hydrocarbon-rich Williston, Illinois and Michigan basins. The Hudson Bay basin is more than 1000 km wide and contains up to 2 km of Paleozoic sedimentary rocks that overlie Archean and Proterozoic crust of the Trans-Hudson orogen and adjacent cratonic regions (Eaton and Darbyshire, 2009), yet the origin of the basin is still unknown. This study focuses on determining how the Hudson Bay basin formed and on regional crustal structure based on ambient-noise tomography. Two hypotheses for basin formation are tested here. The first is that basin subsidence was triggered by eclogite phase transformation within an orogenic crustal root (Eaton and Darbyshire, 2010); the second suggests, basin subsidence occurred in response to lithospheric extension that resulted in crustal thinning (Hanne et al., 2004). These hypotheses make different predictions about crustal thickness trends that are potentially testable using this approach.

Method

Twenty-one months of continuous ambient-noise recordings have been acquired from 37 broadband seismograph stations that encircle Hudson Bay. These stations are part of the Hudson Bay Lithospheric Experiment (HuBLE), an international project that is currently operating more than 40 broadband seismograph stations around the periphery of the Bay. We follow well-established data processing methods described by Bensen et al. (2007). First, the data were split and decimated by cutting the recordings into individual one-day records and resampling to 1 sample per second. Next, we removed the daily trend, mean and instrument response from the raw signals. A one-bit normalization procedure was then applied to remove unwanted earthquake signals and instrument irregularities, which obstruct the broadband ambient-noise signal. This is followed by spectral normalization, which acts to broaden the frequency band of the noise data, and then bandpass filtering between 0.005Hz and 0.3Hz.

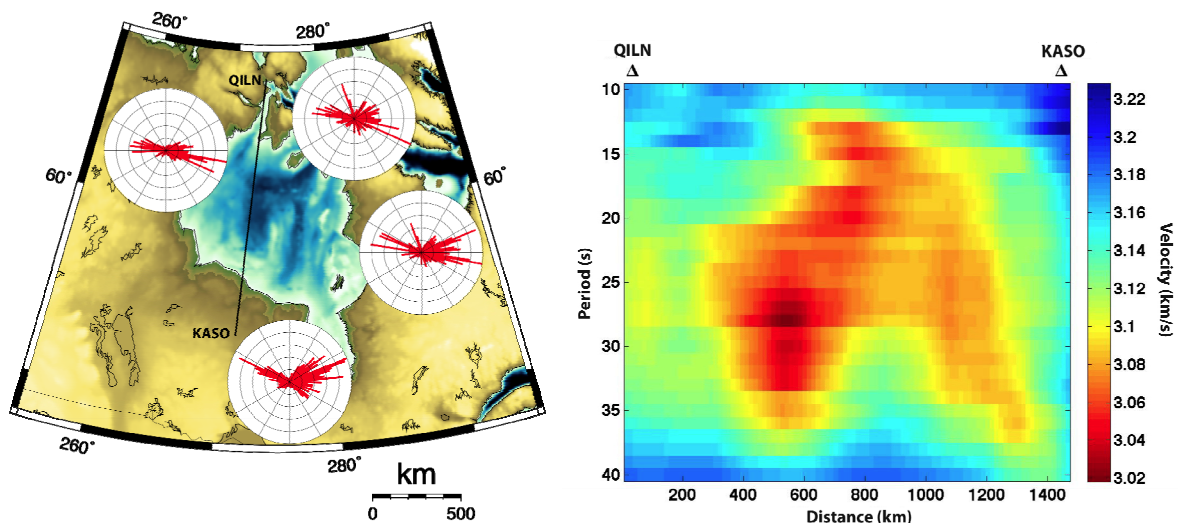


Figure 1 (a) shows the directional compass plots of ambient noise sources. The red lines point to source origin. Significant asymmetry can be seen, with strongest sources coming from the east coast. (b) Shows a tomographic pseudo-section crossing Hudson Bay from North to South (black line on left image). Red zones indicate slow velocities and blue zone indicate fast velocities. Periods correspond approximately with depth of peak sensitivity of resolution kernel in km (Lin et al., 2007).

After the time series are processed for each day, cross-correlations are performed between all possible station pairs and all available daily records. In general, averaging of cross-correlation signals over long time periods (typically 6 months or more) is necessary for emergence of so-called empirical Green functions (EGFs) with usable signal-to-noise ratio (SNR). Careful inspection of our stacked cross-correlation functions, however, reveals a persistent asymmetry in which one half has significantly higher SNR than the other (Fig 1a). As an alternative to averaging the stacked cross-

correlation functions, we have adopted an approach in which either the causal or (time-reversed) acausal half is selected based on which has the absolute highest SNR, yielding better-defined dispersion ridges as compared with the conventional method. Rayleigh-wave group-velocity dispersion measurements in the period range of 5-40 s, estimated from the EGFs using frequency-time analysis, as described by Levshin et al. (1989), are used here to invert construct tomographic images based on the method of Barmin et al. (2001).

To look for source directionality in our data, we have computed rose diagrams of SNR for groups of stations situated in quadrants around Hudson Bay (Fig 1a). To further analyse source directionality SNR calculations are made for different period bands, which represent the microseism band (5-20s), and for season. The rose diagrams are arranged on an azimuthal map projection so that dominant directions can be extrapolated linearly to the nearest coastal region, rather than along a curved great-circle path. The rose diagrams are computed from both the causal and acausal parts of the cross-correlation functions, showing the asymmetry of seismic noise sources in the region.

Conclusions

Rose diagrams showing azimuthal directions of ambient noise sources (Fig 1a) indicate strong influence from both the west coast (near southern Alaska) and the east coast (near Labrador), with no apparent influence for Hudson Bay. Rose plots disaggregated by season and period (not shown here), show little variation between summer and winter, but significant dependence on period. Tomographic maps (not shown here) are plotted for a periods ranging from 5-40s. These periods can be considered as representative for depths from the upper crust to the uppermost mantle, as the average crustal thickness around Hudson Bay is 38 ± 1 km (Thompson et al., 2010). Results show a horseshoe-like geometry of high velocity in southeastern Hudson Bay corresponding to the Archean Superior craton. A low velocity feature lies beneath the Hudson Bay basin, shrinking with period up to ~35s period. A tomographic pseudo section, corresponding to stations QILN and KASO, crossing Hudson Bay in a North-South direction is shown in Fig1b. The pseudo section is extracted from tomographic maps. The low velocity feature beneath Hudson Bay is highlighted here, showing a strong uplift (~3km) beneath the Hudson Bay basin. This result provides the first compelling direct evidence for crustal thinning beneath the basin, allowing us to reject the proposed model for basin subsidence triggered by eclogitization of a crustal root.

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